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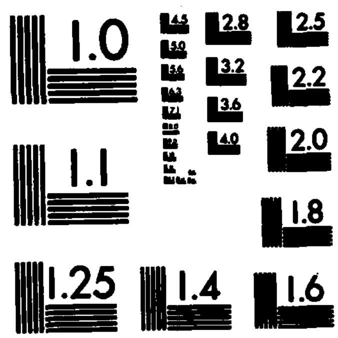

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Operational Loads Measurement and Evaluation

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

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AGARD Report No.704

OPERATIONAL LOADS MEASUREMENT AND EVALUATION

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PREFACE

It has become common practice to fit recording accelerometers, "fatigue meters", to fixed wing military aircraft in order to obtain service data on fatigue loads associated with symmetric manoeuvres and normal gusts. However, the structural airworthiness assurance offered by such relatively simple monitoring systems is far from complete; current experience indicates that serious fatigue failures are more common than structural failures due to inadequate static strength. A number of loading actions imposed by asymmetric manoeuvres, control system inputs and relatively high-frequency dynamic effects will be imperfectly understood or entirely unquantifiable by use of such instrumentation. Moreover, current trends in aircraft design and operation must increase the total number of design cases requiring identification and clearance, the need for more accurate prediction of in-service loads and the degree of uncertainty regarding actual load spectra. These trends include:

Increased manoeuvre capability and terrain following.
Multiple aircraft roles.
Changes of role and new operational tactics.
In-flight configuration changes.
Active control technology.
Continued pressure for airframe weight reduction.
Use of anisotropic and low-ductility materials.

At its Fall 1981 Meeting in Noordwijkerhout, Netherlands the AGARD Structures and Materials Panel formed an ad hoc Group to consider the topic of Aircraft Loads Data, subsequently retitled Operational Loads Data. This Group met both in the Netherlands and at the Spring 1982 Meeting in Brussels, Belgium. At the latter, the Panel agreed to the formation of a Sub-Committee to cover the same topic, with a Specialists' Meeting to discuss advanced loads data acquisition concepts planned for Spring 1984. The subject was considered to divide into two major branches: the first, data acquisition and analysis to confirm design loads; the second, extended analysis for fatigue life determination and monitoring systems development.

This Report contains two pilot papers given at the Brussels Meeting. Taken together, they characterise both the division into design loads and fatigue analysis, and differing approaches to the determination of operational loads and structural stresses.

D.M.F.BRIGHT
Wing Commander, Royal Air Force
Chairman, Sub-Committee on Operational Loads Data

CONTENTS

NOFLOMP - THE NIMROD OPERATIONAL FLIGHT LOAD MEASUREMENT PROGRAMME

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SUMMARY

The inadequacies of the fatigue meter (a counting accelerometer) cannot be overcome by another simple device. Considerable instrumentation is needed on at least one aircraft in a fleet if the fatigue damage to the wing, tail unit, fuselage and undercarriage is to be properly assessed, especially if the aircraft operates in a role which necessitates unusual manoeuvres.

This paper describes the installation and calibration of such a system in an aircraft in RAF service, and mentions some of the problems which came to light. The analysis of the data obtained from the flight records is discussed, together with possible future developments.

1 INTRODUCTION

One of the difficulties in designing a military aircraft is that of predicting what manoeuvres will be adopted in the course of its normal service use, especially when these manoeuvres affect the fatigue life. The problem is particularly acute if the aircraft is being designed to fulfil a new role or if it contains some new equipment. A good example is the Harrier: "viffing" (vectoring-in-flight) was invented by a service pilot and is now a standard evasive manoeuvre. But when the aircraft was designed, the manoeuvre did not even exist.

Sometimes unusual manoeuvres arise to overcome a design shortcoming. Pilots of a particular strike aircraft, flying low over the sea, often needed to clear the windscreen, but the screen washer gave poor coverage. The standard procedure was to wag the rudder to initiate a "fishtail" manoeuvre, which resulted in the washer fluid being evenly spread over the glass. Unfortunately the manoeuvre also caused considerable fatigue damage to the fin, the cause of which remained a mystery for some time.

When we designed Nimrod - the Maritime Reconnaissance aicraft of the Royal Air Force - we had not fully appreciated the severity of some specialised manoeuvres which would occur during routine flying. Once the aircraft went into service, high fatigue meter counts on particular flights brought the matter to our attention.

Other problems arose from the practice of running up the engines to full power against the brakes, a practice which had an adverse effect on the fatigue life of some undercarriage components. The undercarriage fatigue life was also affected by a marked increase in the number of landings per flying hour compared with the original design aim.

In order that the fatigue life of the airframe is adequately established and monitored, we need accurate data on how the aircraft is really used, and this is the purpose of NOFLoMP. It is not a case of "Find out what the RAF are doing and tell them to stop it", but a genuine "need to know" so that we can advise on the inspections, modifications, etc needed to keep Nimrods flying for another 20 years.

2 FATIGUE EVALUATION

Currently the standard method for monitoring fatigue life consumption in RAF aircraft is by means of a fatigue meter. The counts of various levels of normal acceleration read from the meter are fed into a formula based on an S-N curve (preferably derived from a full-scale test), and the cumulative damage is calculated.

The fatigue meter is a most useful instrument, and the regular supply of returns from the operator to the manufacturer is a valuable source of data. But the fatigue meter has several shortcomings. The most serious are (a) it tells us only what is happening at the centre of gravity, and (b) it tells us only about symmetric manoeuvres. For short, stiff wings, the normal acceleration at the cg is a good guide to the bending stresses in the wing caused by symmetric manoeuvres. In a flexible wing like Nimrod's, where the fuel mass varies enormously throughout the flight, the fatigue meter can give very misleading data. Moreover, the aircraft can roll or yaw without a single count appearing on the meter, yet the stresses in the wing can be changing rapidly. It is, of course, the variation in stress which causes fatigue. When we come to the fuselage, fin, tailplane and undercarriage, the fatigue meter tells us nothing.

Fatigue evaluation needs two pieces of data: the fatigue resistance of the structure and the load spectrum, that is the number of times each level of load is applied. Currently our knowledge of both is limited.

The Nimrod structure is based on the Comet 4 airliner for which the fatigue resistance was established by a major test some years ago. We expect to conduct a new fatigue test on a Nimrod wing, and one aspect of NOFLoMP will be to provide data for such a test. The immediate purpose, however, is to provide a realistic load spectrum from which we can calculate more accurately the fatigue life of the fleet. This paper describes how we are achieving this objective.

3 MEASURING DEVICES

We cannot measure loads directly; the best we can do is to determine strains, that is the amount by which the metal of the airframe stretches or contracts when it is loaded. By calibrating the aircraft on the ground we can then deduce what loads are being experienced in flight. Even strains are too small to be measured directly; we have to use strain gauges which measure the change of electrical resistance as the local structure changes length, but one advantage of an electrical system is that it can transmit data continuously to a central recording point. The "active" strain gauges have to be compared with identical gauges on unloaded coupons in the same locality. The assembly of gauges required to measure the strain at any one point is called a "bridge".

There are 98 such bridges on the Nimrod in question, XV 227. For load measurement purposes, there are a total of 16 bridges per wing so that we can deduce the bending moment, shear force and torque at 4 sections (port and starboard). Aileron and flap loads are also measured. Additionally, 27 bridges are installed to measure the stresses at several locations known to be fatigue-sensitive.

There are bridges on the undercarriage so that vertical, drag and side loads can be measured. Additionally, the brake torque rods have bridges which measure the braking effort. The wing-to-fuselage attachments have bridges which give an indication of the fuselage bending moments and shear forces.

The tailplane is instrumented like the wing, so that it is possible to deduce the bending moments and torques at three stations on the port side, with a check on the root station on the starboard side. There are bridges at the base of the fin, and finally there are two reference bridges to act as controls.

When measuring loads, they must be related to the manoeuvres which the aircraft is performing at the time. There are therefore 17 accelerometers to describe the response of the aircraft. At the aircraft centre of gravity, these measure the accelerations laterally, longitudinally and vertically. On the wing they indicate the accelerations of the underwing pods and the engines, whilst at the tips of the wing, tailplane and fin and in the rear fuselage they indicate the response of the extremities.

Additionally, some 22 instrumentation and aircraft parameters such as speed, altitude, control surface angles, rate of pitch, roll and yaw, yaw damper output, autopilot mode, flap position, airbrake position and cabin pressure are recorded.

The strain gauge bridges, accelerometers and aircraft parameters are sampled at either 70 or 140 times per second, giving a total of 45 million pieces of information per hour. Clearly, handling all this information is a mammoth task. The information from the instrumentation is digitised, amplified and recorded on 14 track tape. The tape recorder runs at 48 mm per second, and one tape is sufficient for a 12 hour flight. The recorder is located in the crew's quarters, and the control panel is located at the Flight Engineer's station.

4 SELECTION OF BRIDGE LOCATIONS

In selecting the locations for the load measuring bridges it was necessary to establish that they responded strongly to the input they were measuring and were not influenced unduly by other inputs. Thus if a bridge was intended to measure bending moment, it should not respond to torsion, or vice versa.

Fortunately, a retired RAF Comet was available at RAE Farnborough, which was already being used to measure the stresses in the wing after repairs had been effected. A loading rig was thus available, and this was used to ensure that the best strain gauge positions were found. By a process of trial and error optimum locations were established, so that bridges could be installed on XV 227 with confidence that they would not require adjustments which would delay its delivery to RAF.

Strain gauges are delicate instruments which are easily damaged. From one point of view, they should be installed early in the aircraft build sequence so that they can be placed on internal structure where they are given the best protection from the environment. An opposing view is that the gauges and their associated wiring are vulnerable to damage by workshop personnel if they are positioned too early, and they should therefore be installed as late as possible, even if this means that they are fixed to the outer surface.

In the case of XV 227, a compromise was made. The aircraft had been returned to the manufacturer for an internal refit which involved some structural dismantling. Some gauges were therefore fixed to internal structure, but the majority were placed externally.

5 CALIBRATION

Before putting XV 227 into service it was necessary to calibrate the instrumentation, that is to say the response of the strain gauge bridges to known load inputs had to be determined.

Wherever possible, components were removed from the airframe and calibrated in a testing machine. This procedure was followed for small items such as control rods, brake rods and the wing/fuselage attachment links. Other items such as the flap jacks and undercarriage side stays were calibrated in situ against known inputs.

Bridges on the wing, fuselage, tailplane and fin had to be calibrated by putting the complete aircraft on jacks and applying a series of loads at various locations. At least 6 tests were required for each of the 8 wing sections, the maximum loading being roughly that corresponding to a 1.4g pull-up manoeuvre.

Besides applying the loads externally, the gauges were also calibrated against different fuel levels with the aircraft standing on its jacks. It was also necessary to ensure that fuel tank pressurisation and cabin pressurisation had no effect on the load measuring bridges.

6 TEST FLIGHTS

One final task remained before XV 227 could be delivered - that of proving that the instrumentation and recording gear worked when the aircraft was airborne. Moreover, it was necessary to ensure that none of the existing avionic systems on board suffered from (or caused) any interference.

These flights were incorporated into the normal pre-delivery schedule and appeared completely satisfactory.

7 ANALYSIS

The tapes recorded in service are returned to the manufacturer, and the major task then begins - that of analysis.

The process starts by transforming the recording from the flight tape on to computer compatible tape (CCT). Up to 32 such tapes can be generated from one aircraft tape.

The vast amount of data has then to be "compressed" by eliminating all "non-damaging" events, ie those minor disturbances which are reckoned not to cause fatigue. "Trigger" levels are chosen which indicate a chosen degree of structural activity, and the compressed tape includes only those activities of a higher level than the trigger. The criterion for judging non-damaging events was originally based on the levels of normal and lateral acceleration at the aircraft cg. It was quickly found, however, that the fin was often very "active" even though the lateral acceleration at the cg was low, and it proved necessary to include the fin bending stress as a trigger.

Studies were then necessary with various trigger settings in order to determine how much fatigue damage had been eliminated at various important stations on the structure. Although it had been hoped to achieve compression ratios of 20:1, in practice ratios of 4:1 are more common. There is thus a large quantity of residual data which requires processing to obtain the fatigue damage, and a computer is dedicated to this task.

A more serious problem surfaced in the first recordings, due to interference from high frequency radio transmissions. Despite the earlier trials, which should have eliminated such interference, HF break-through was evident in the recordings as a local shift in the datum level. Since it has proved impossible to screen the equipment from this interference, the computer is now programmed to eliminate those portions of the recording which show this shift. This means that some portions of each flight are ignored, but in most cases the periods of HF transmission are very brief.

The analysis follows the Range Mean Pairs technique, peaks and troughs in the strain record being "paired" to give an amplitude about a local mean value, thus enabling a cumulative damage calculation to be made. In the absence of a better technique, Miner's Damage Law has to be used for this purpose, and this is probably the weakest link in the chain of events.

However, the more representative the fatigue test loading can be, the less the error which is introduced by this step in the analysis. In the ideal case, where the test loading exactly reproduced the flight loads, the error would be zero. There is thus a "chicken-and-egg" situation here: on the one hand, the flight load measurement programme is needed to provide loads for a representative fatigue test; on the other hand, the use of the flight load measurement programme for fatigue damage calculations pre-supposes a result from such a fatigue test.

In these circumstances, the NOFLoMP approach appears to be the best compromise. Fatigue test results from a similar aircraft (the Comet) are used to provide provisional information on the fatigue resistance of the structure; this enables an initial estimate of fatigue life consumption to be made from the loads measurement exercise. A new fatigue test using a more representative structure and the loads derived from NOFLoMP will then provide a revised estimate of the fatigue resistance, allowing an adjustment to be made to the life consumption estimates.

8 FURTHER DEVELOPMENTS

Clearly such comprehensive instrumentation as that described above, even if it is limited to one aircraft in a fleet, is expensive to install and maintain. The analysis is also expensive in computer time, to the extent that it needs a dedicated computer. A simplified approach is thus needed if flight measurement is to become the standard means for calculating fatigue damage.

A study is therefore proposed which will determine the influence of the various parameters involved in the analysis. If this study were to show, for example, that an accelerometer in the rear fuselage was a good indicator of tailplane load, then a counting accelerometer in the same location might be used as a reliable guide to tailplane fatigue damage. By adopting this approach to other important structural components, a simplified instrumentation package could be devised which could be fitted to more than one sample, enabling a more rapid assessment to be made of the fatigue life consumption on individual aircraft.

9 CONCLUSION

A comprehensive installation on an RAF aircraft has demonstrated the feasibility of measuring sufficient parameters to enable the fatigue damage to be calculated at a number of locations throughout the structure.

The analysis of the data is a complex procedure requiring a dedicated computer and "compression" of the data to a convenient level has proved difficult without significant effect on the accuracy of the analysis. However, once sufficient flight records have been analysed, a parametric study could be used to devise a reduced installation combined with an analytical procedure which would give a more rapid read-out of fatigue damage at critical points in the airframe on several, if not all, the aircraft in a fleet.

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LOAD EVALUATION FROM OPERATIONAL MANOEUVRES

by
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SUMMARY

The loads resulting from manoeuvres are largely determined independently of the manoeuvres actually performed in operation or during missions. The assumption is that the manoeuvres defined in the specifications cover all manoeuvres occurring in operation. The introduction of the fly-by-wire and/or active control technology makes this philosophy inadequate, though.

The specifications give the time history of cockpit control deflections and, in accordance with the category of aircraft involved, numerically define several essential load parameters for determination of the load level. This procedure does not directly correlate the design loads with the manoeuvre loads that will occur during aircraft operation; merely a few parameters are predetermined as structural operating limits, for example airspeed, vertical load factor, roll rate etc.

In practice, manoeuvres, especially combat manoeuvres, are flown in accordance with given, practiced rules that lead to a specified motion of the aircraft in space. This fact gives rise to the idea of analysing the manoeuvres and deriving the loads from them. This procedure is shown by an example.

1. INTRODUCTION

Aircraft structures are designed in accordance with the relevant regulations and based on a philosophy defining the load level so as to cover all loads expected in service. No explicit mention is made of the correlation between design loads and loads in service.

Some design loads are determined by defining the control surface deflections, to permit calculation of the aircraft response and thus of the manoeuvre loads. For other load cases, the load level is predetermined by defined limit values, e.q. by the load factor (n_z) for symmetric load cases and by the roll rate (p) for rolling manoeuvres.

A summary is given of the operational data and methods used. The open questions have been commented upon and possible solutions put forward. Finally, a possible solution for deriving design loads from operational data is presented, its aim being to minimize the expenditure required for data measurement and analysis.

2. STATE OF THE ART

It has become common practice to fit accelerometer systems (fatigue meters) to fixed wing aircraft to obtain service data on fatigue loading actions associated with symmetric manoeuvres and normal gusts. However, recent experience suggest that the structural airworthiness protection afforded by such systems is far from being complete. The following operational parameters usually are recorded and compiled:

- number of flights and/or flight hours
- configuration and mass of the aircraft
- vertical acceleration at the C.G. of the aircraft

A lot of such data is available but the evaluation procedures are different with respect to the separation of the data by duties, missions, manoeuvres etc. The vertical acceleration (vertical load factor) at the C.G. is the only main load parameter available and is analysed in different ways.

These data are usually applied as spectra "cu ulative fr uency distributions of incremental load factors" for fatigue life certi ation. ever, there is no explicit information available about the probability of loa to xceedances referred to the design load factor, which is the criterion for stat design loads, especially in symmetric flight conditions. Asking for the relation of the design conditions to the extreme operational conditions [1] no margin is given between main design parameters (speed, load factor, roll rate) and operational ones. First some facts should be given to show which data are available and how they might be used for structural design.

2.1 Symmetric flight conditions

- For symmetric loads, especially for the wing, at present the load factor n_z is the best indicator for the derivation of load spectra for wing loads i.e. bending.

- But what about the tailplane?
  An attempt has been made to find a relation between measured vertical incremental acceleration at the C.G. and the incremental tailplane load by Prof. Buxbaum in 1972 for one aircraft type of the GAF [2] .

Although only increments were taken into account and although only symmetric bending moments were correlated with vertical accelerations, the result might be called a low correlation (Fig.1). That is, nevertheless, what one might have anticipated, because the load-time history at the tailplane cannot always be in phase with the C.G. acceleration. This is not only due to dynamic effects but is caused also from the fact that for generating a manoeuvre acceleration at the C.G. of the airplane a stabilizer deflection and thus a bending moment increment has to precede it. There may, moreover, be loads on the tailplane without any measurable response in the C.G. and also C.G. accelerations without any effect on the symmetric tail load. This is the reason why a correlation between C.G. accelerations and bending moment increments at the tailplane can never be sufficient on a deterministic basis.

A possibility using statistical analysis has been found which allows one to derive the relationship with certain assumptions from the respective cumulative frequency distributions. It has been assumed that on average the ratio of movements of the airplane in the vertical direction to those in other directions will remain the same. This statement can possibly be met for the measurement program by distinguishing between flights performed under constant conditions (aircraft configuration, weight, mission, duty). Then the conclusion can be drawn that the ratio between those values of the cumulative frequency distributions, which have occurred with equal cumulative number of occurrences, will be constant. This allows us to establish a correlation between C.G. acceleration increments and tailplane loads from the respective cumulative frequency distributions, just by plotting those values which have occurred with the same cumulative frequency per flight (Fig.2).

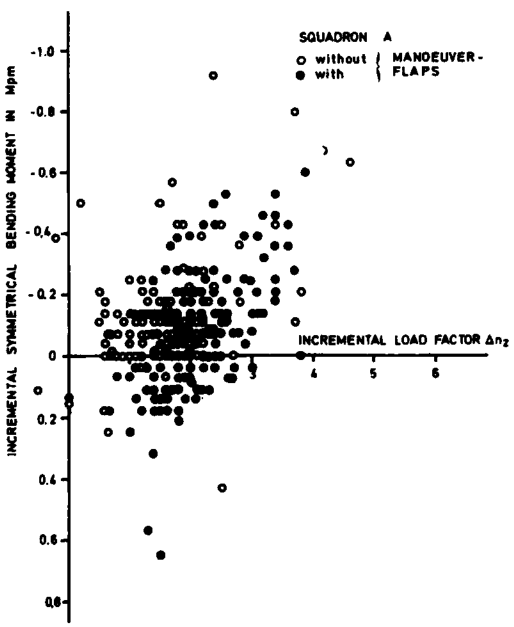

FIG. 1 SIMULTANEOUSLY OCCURRING VALUES OF INCREMENTS OF SYMMETRIC STABILIZER BENDING MOMENT AND LOAD FACTOR

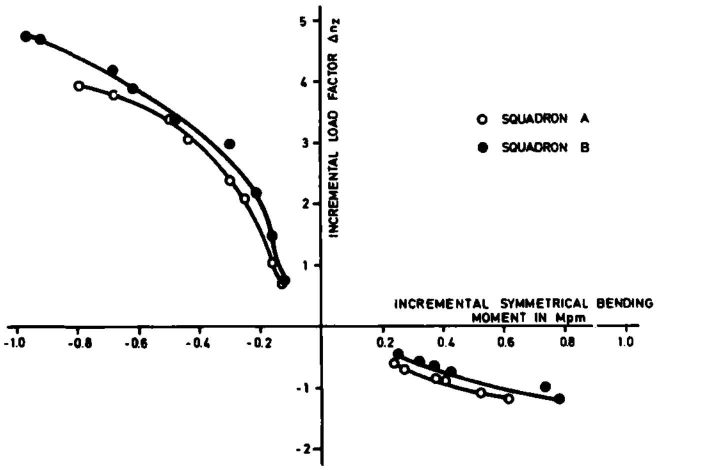

FIG. 2 INCREMENTAL LOAD FACTORS VERSUS INCREMENTAL SYMMETRIC STABILIZER BENDING MOMENTS OCCURRING WITH EQUAL RELATIVE CUMULATIVE FREQUENCIES

ımetric flight conditions

ɔr asymmetric flight conditions due to rolling and yawing manoeuvres, certainly ıe symmetric loads are included in the load spectra derived from vertical :celerations in the C.G. But we do not know the load portion due to rolling and ıwing.

ɜymmetric loads on tailplanes
ɔad measurements on tailplanes of civil and military transport airplanes during Light tests have indicated that asymmetric load distributions specified in ɜveral regulations are not sufficient for design.

ıe asymmetric load distribution required in regulations is shown in table 1. In ıble 2 some relations of extreme values to required values of rolling moments ı tailplane are given.

Regulation	Distribution %	Flight condition
MIL-A-8861	5o / 15o	speeds at V_A or buffet
	85 / 115	others
AIR 2oo4/D	75 / 1oo	symmetric
/E	5o / 1oo	asymmetric
Av.P 97o	no specific requirement*	
FAR 25	8o / 1oo	symmetric
JAR 25	8o / 1oo	symmetric

*) distribution to be decided in consultation between contractor and airworthiness authority

Table 1 ASYMMETRIC LOAD DISTRIBUTION ON TAILPLANE

	Regulation applied	Extreme value / Required value
C16o	AIR 2oo4/D	2.o
VFW 614	FAR 25	1.5
A 3oo	FAR 25	≈ 4.o

Table 2 RELATION OF ROLLING MOMENTS ON TAILPLANE

ınd Loads

ɜeveral regulations 2o to 5o load cases are defined dealing with loads on landing ach one of these load cases might become a design case for the undercarriage or the ɜ structure. For a rough but interesting comparison it is sufficient to consider :ew load cases which often usually lead to the design of the landing gear. For : with nose gear the cases are:

ɜpin-up load at small angles of attack

rerification of the reserve energy ability.

jenerally is the most important one for the structural design of the landing ıse 2 is determinative for the stroke of the shock absorber. The differences :equirements for FAR 25, MIL-8862, and BCAR are given in table 3. The following ıre worth noting:

ıe design speeds both vertical and horizontal, are nearly the same

ıe different definition of the equivalent mass for the nose gear in BCAR ıich results in a higher load level

ıe reduced factor of safety in MIL-A-8862 which has been changed to 1.5 in :L-A-oo8862.

CASE	CONDITIONS	FAR25	MIL 8862 without Trainer	BCAR $W > 5.7t$
Maximum Spin - up Loads (often determining for U/C weight)	Conditions valid for all regulations	Lift = A/C Weight; $P_y = 0$ C.G. : For nose gear forward, for main gear aft Attitude: Corresponding to a three-point landing		
	A/C Weight	$W = W_L + W_{TO}$	$W = W_L \div W_{L\,max}$	as FAR
	Method of Analysis	separate for nose and main gear	analysis for complete A/C	as FAR
	Aquivalent mass for separated consideration for nose- and main gear	$W_{Main} = W/2$ $W_{Nose} = W \cdot b/(a+b)$	not applicable	$W_{Main} = W/2$ $W_{Nose} = W \cdot (b+0.4h)/(a+b)$
	Design landing speed V_x (m/s)	$1.25 \cdot V_{S0}$ (ISA + 23°)	$1.2 \cdot V_{S0}$	undefined
	Design sinking speed V_z (m/s)	3.05 at W_L 1.83 at W_{To}	3.05 at W_L $3.05 \cdot \sqrt{1/1,15}$ at $1.15 \cdot W_L$ 1.83 at $W_{L\,max}$	$2.14 < 1.53 + 0.06\,V_{S0} \leq$ ≤ 3.05 at W_L 1.83 at W_{To}
	Friction coefficient tire - ground	admissible: $\mu_x \leq 0.8$ or $\mu_x = 0.55$, ANC 2	$\mu_x = 0.55$	$\mu_x = 0.4$ $\mu_y = 0.25$
	Max. vertical load F_z	$F_{z\,eff.}$ at the time of spin-up	as FAR	$F_z = K \cdot F_{z\,max}$ $K = 0.55 \div 0.75$
	Max. spin-up load F_x	ANC 2, admissible is: $F_x = K_{sb}(\mu_x \cdot \cos\gamma - \sin\gamma) \cdot P_z$ $K_{sb} = 1.4$ F_x = normal to U/C	as FAR	$0.8 \cdot F_z$ F_x parallel to ground
	Factor of safety j	1.5	1.0	1.5
Reserve energy absorbtion capacity (often determining for the stroke of U/C)		$V_z = 1.2 \cdot V_z$ limit $W = W_L$ V_x undefined $j = 1.0$ other conditions as above to be verified by tests only	MIL 6053 $V_z = 1.25 \cdot V_z$ limit $W = W_L$; $V_x = 1.2\,V_{so}$ $j = 1.0$ other conditions as above to be verified by tests only	$V_z = 1.2 \cdot V_z$ limit $j = 1.0$ other conditions as above

TABLE 3 : COMPARISON OF REGULATIONS FOR 2 DESIGN LOAD CASES FOR CONVENTIONAL AIRPLANES WITH NOSE GEAR

3. PROBLEMS TO BE SOLVED

A number of loading actions imposed by asymmetric manoeuvres, control system inputs, ground manoeuvres and relatively high-frequency dynamic effects may be imperfectly understood or inaccurately quantified. To ensure that design, testing and fatigue calculations are soundly based, some direct measurements in service or derivation of operational loads are now increasingly necessary.

Current trends towards increased combat manoeuvre or lift capability, terrain following, use of active control technology and various tactical developments make the need for additional measurements and activities in acquisition and analysis of operational data even more pressing. This means that we should look for parameters which are suitable for the derivation of the loads on structural components of the aircraft and which can be measured with little expense.

The parameters of aircraft movement and control deflections are necessary to determine the loads on the aircraft. These data should be recorded in service, collected and analysed in a specified order. The compilation and analysis should distinguish between different missions and particular manoeuvres.

3.1 Symmetric Flight Conditions

The vertical load factor can be considered approximately as the main indicator for the wing load during symmetric flight conditions. For this reason a lot of measurements have been made, compiled and published generally as cumulative spectra for fatigue design.

However, up to now no suitable indicators have been found for:

- asymmetric wing loads
- the derivation of loads on other structural components e.g. tailplane, fuselage etc.

Other potential parameters (n_y, β, ω_x) have been measured and analysed but only in special cases for individual aircraft.

3.2 Asymmetric Flight Conditions

Asymmetric loads are more complex especially for combat aircraft, e.g. due to rolling manoeuvres. For design of the structure the correlation between the symmetric loads (Z) and the asymmetric (Y), the values of the load components (shear, bending, torsion), which will be expected simultaneously, are needed.

3.3 Design Requirements, - Regulations applied

In the design requirements [3,4] several flight conditions are specified distinguishing between:

- symmetric flight conditions - pitching manoeuvres

- asymmetric flight conditions - yawing manoeuvres
  - rolling manoeuvres

For these manoeuvres the displacements of the cockpit control are specified. Fig. 3 shows the longitutidinal control displacement. For asymmetric conditions in particular, the initial symmetric load level is specified by the vertical load factor.

- yawing manoeuvres $n_z = 1.0$
- rolling manoeuvres $n_z = 0.8\ n_{z(max)}$

We are not sure if these levels are sufficient and what are the values during the manoeuvre? The loads resulting from aircraft response and the aerodynamic influence of the control deflection are to be considered as design limit loads.

Up to now no analyses have been made comparing these design loads with operational loads in service, with respect to the load level and the correlation between the components of loads. Thus the philosophy of the specified design conditions is that all operational loads occurring in service are to be assumed as covered by the specified design conditions in the regulations applied (MIL-A-886o series, AIR 2oo4/D, Av.P.97o).

We have the same lack of knowledge for load spectra. There are hardly any parameters available reliable enough to predict load spectra expected in service for structural components mainly stressed by asymmetric loads.

3.4 Aircraft with Active Control

For Controlled Configured Aircraft the load level generally is less than for conventional controlled aircraft. In particular, the application of Manoeuvre Load Control (MLC) leads to a modification of the load distribution on the aircraft with the result that extreme loads on particular structural components will be reduced. But on average more control surfaces are involved, each with higher numbers of cycles.

In the appropriate regulations no distinction is made between aircraft with active control and conventional aircraft. This means that there will be a difference between the primary cockpit control displacement and the control surface deflection. This difference depends on the influence of the active control system. Fig. 4 shows the difference of cockpit control displacement and control surface deflection of a modern combat aircraft.

If the control deflection time history and that of the primary cockpit control have no similarity, the task of determining the extreme loads on the main structural components is very complex. In addition the difficulties in establishing the load spectra will increase.

3.5 Ground Loads

From our experience we suggest the following:

- Calculation of landing loads should not be made with reduced masses of the airplane because the loads on nose gear may be about 2o% too low. MIL-A-oo8862 already requires the designer to determine the undercarriage loads by dynamic response calculations on the complete aircraft.

- For asymmetric (drift) landing no load analysis for the complete aircraft is required. The design loads (vertical reaction and side load) are specified by factors which are not sufficient for design, especially for aircraft with flexible gears when a cornering force at the tyre results from the gear deflection due to vertical or spin up loading.

- The coefficients of sliding friction between the tyre and the surface are specified differently in the various regulations. A rationalisation of the coefficients would be timely.

- A dynamic braking case for the complete aircraft should be included. Dynamic response effects may lead to higher loads on the nose gear.

- Dynamic response effects of the elastic gear structure (additional to the shock absorber) and tyre should be included in a rational landing load analysis, not only for spin up and spring back but also for other important directions as sideways, torsional or even vertical. Overshoot effects of up to 5o% were found on different aircraft.

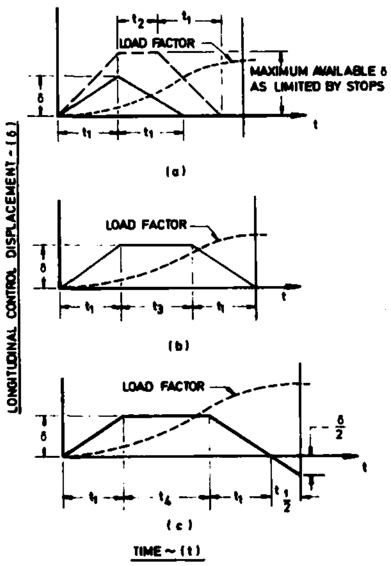

FIG. 3 COCKPIT LONGITUDINAL CONTROL DISPLACEMENT MIL - A -008861A

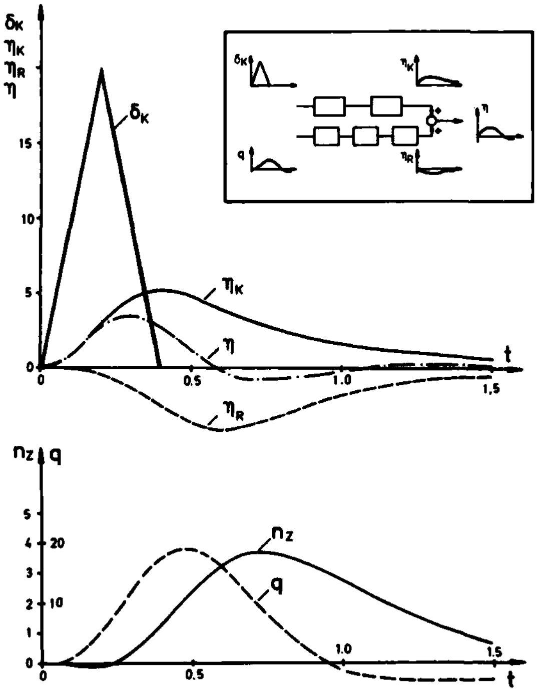

FIG. 4 DIFFERENCE BETWEEN COCKPIT CONTROL AND ELEVATOR DEFLECTION TIME HISTORY

4. PARTICULAR SOLUTIONS

In the past operational loads were predominantly checked by measurement of the main load parameters. These parameters have been established and some of them are published. The main load parameters are:

- the normal load factor in flight

- the angle of sideslip and/or the transverse load factor in asymmetric flight, especially in yawing conditions

- the roll rate in rolling manoeuvres

- the sinking speed for (symmetric) landing

- the bank angle and the yaw angle for lateral ground loads

On the basis of these spectra the probability of occurrences for the main load parameters can be defined for each type of mission and manoeuvre. For a specified probability of occurences (once per aircraft life or once per 1o aircraft lives) the main design load parameter can be determined as the basis for the design load level.

4.1 For Derivation of Design Loads

(a) Extreme value distribution of loads

In 1967 O. Buxbaum, LBF, suggested a method for determining design loads from extreme values of frequency distributions [5]. This method is capable of deriving design loads by means of a statistical evaluation of the extreme values, in cases where the range, the maximum value, and the scatter of the spectrum may be properly assumed.

(b) Influence of taxi requirements

With respect to runway roughness, especially damaged and repaired runways, it should be decided whether or not the taxi loads should be included in the design requirements.

(c) Measurement and analysis of the movement in flight for special operational manoeuvres

Data for manoeuvres practised in NATO nations (break, high-g-barrel roll, ...) should be recorded in a way that makes it possible to analyse the main load parameters which occur simultaneously. Such measurements, compiled in a specified order containing correlated parameters of movement, can be analysed for several aspects

- establishing of extreme value distributions

- normalising the main manoeuvre parameters

- evaluating the measured parameters with the aim of finding those which are most relevant for load estimation purposes.

4.2 For Fatigue Monitoring and Life Prediction

Life monitoring is only as good as the knowledge of the loads with respect to the magnitude and the frequency, namely the monitored and expected load parameters in service. The following solutions are possible:

(a) Realisation and evaluation of long time measurements of loads on main structural components separated into different missions (Interdiction, Close Air Support, ... etc.)

The evaluation should be done in a normalised manner to ensure the transfer of data to other aircraft in the same category. For normalising purposes essential design data can be used; for example the parameters: load factor, roll rate, design load of a structural component. The recording should include all fatigue-relevant parameters such as weights, C/G-position for

- take off weight
- landing weight
- payload, external stores

data describing the flight profiles

- speed
- altitude
- configuration

This is to enable the assignment of the collected spectra to particular flight configurations. The measurement should allow for the possibility of analysing and presenting the following results:

- Power spectra density distributions

- Cumulative frequency distributions

- Extreme value distributions

- Two dimensional distributions of correlated parameters

Some examples are given in Fig. 5-8:

- A power spectral density distribution of atmospheric turbulence as defined in MIL-spec.[3] for deriving gust loads. Fig. 5

- A cumulative frequency distribution for rolling moment on the tailplane. Fig.6

- An extreme value distribution for rolling moment on the tailplane. Fig. 7

- A two-dimensional distribution of the correlated parameters (drag and vertical load) on the main landing gear. Fig. 8 and Table 4

(b) Measurement of control deflections and the correlation between the controls for several operational manoeuvres

The knowledge of the essential (primary) control deflections and the correlation of one or more secondary control deflections are the basic data from which to predict and check the structural loads due to manoeuvres, especially the asymmetric ones. Combined with the number of cycles for specified levels of deflections for several separate types of manoeuvre, these data are useful for establishing spectra of control deflections and such loads as are influenced by them.

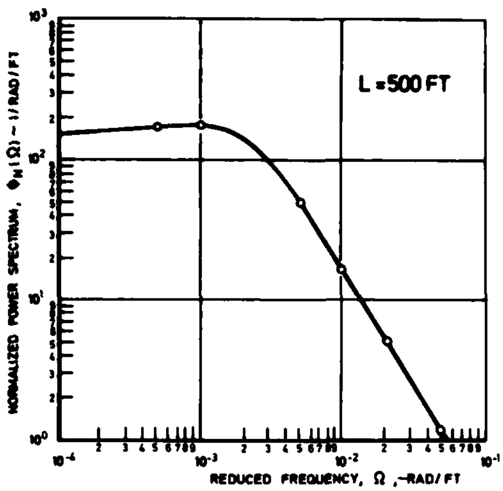

FIG. 5 POWER SPECTRUM OF ATMOSPHERIC TURBULENCE (VON KARMAN)

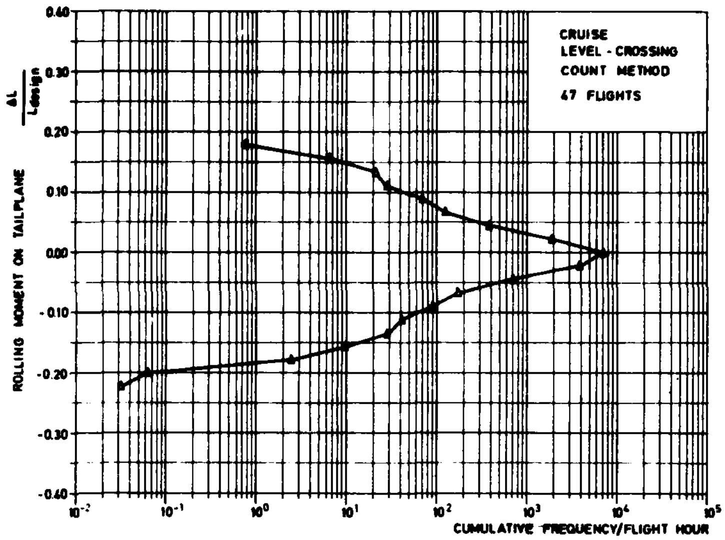

FIG.6 CUMULATIVE FREQUENCY DISTRIBUTION

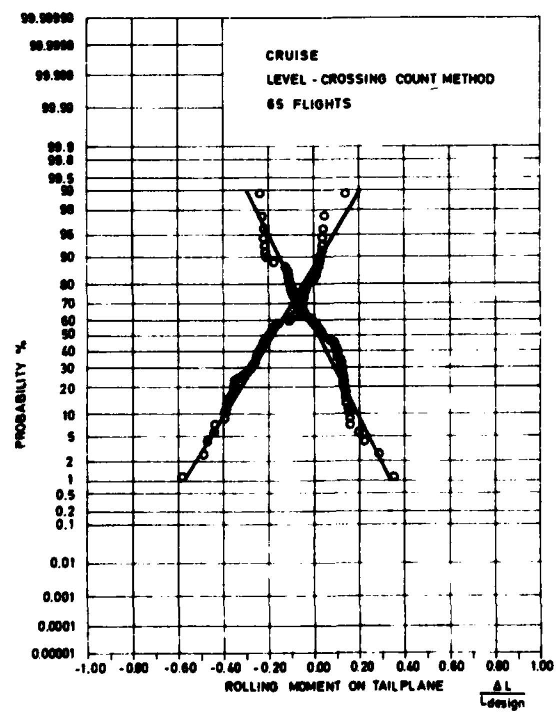

FIG. 7 EXTREME VALUE DISTRIBUTION

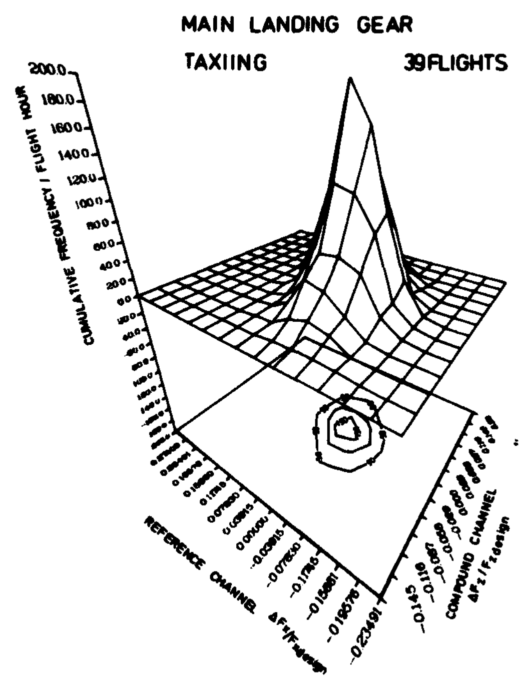

FIG.8 TWO DIMENSIONAL DISTRIBUTION OF CORRELATED PARAMETERS

COMPOUND CHANNEL \ REFERENCE CHANNEL	-o.23	-o.2o	-o.16	-o.12	-o.o8	-o.o4	o.o	o.o4	o.o8	o.12	o.16	o.2o	o.23	o.27	o.31
-o.17	o.	o.	o.	o.	o.	o.	o.	o.	o.	o.	o.	o.	o.	o.	o.
-o.15	o.	o.	1.	3.	4.	4.	4.	1.	1.	o.	o.	o.	o.	o.	o.
-o.12	o.	o.	o.	1.	14.	19.	15.	3.	2.	o.	o.	o.	o.	o.	o.
-o.o9	o.	o.	1.	4.	21.	38.	43.	13.	3.	1.	o.	o.	o.	o.	o.
-o.o6	o.	o.	3.	17.	52.	62.	6o.	23.	6.	1.	o.	o.	o.	o.	o.
-o.o3	o.	o.	3.	21.	81.	112.	118.	58.	17.	3.	o.	o.	o.	o.	o.
o.o	o.	o.	4.	34.	95.	164.	198.	1o4.	46.	2.	o.	o.	o.	o.	o.
o.o3	o.	o.	1.	12.	71.	122.	154.	117.	36.	3.	1.	o.	o.	o.	o.
o.o6	o.	o.	o.	7.	22.	67.	76.	77.	27.	o.	o.	o.	o.	o.	o.
o.o9	o.	o.	o.	3.	14.	32.	46.	22.	14.	1.	o.	o.	o.	o.	o.
o.12	o.	o.	o.	o.	2.	15.	19.	15.	1.	o.	o.	o.	o.	o.	o.
o.15	o.	o.	o.	o.	1.	4.	7.	1.	o.	o.	o.	o.	o.	o.	o.
o.17	o.	o.	o.	o.	1.	1.	2.	o.	o.	o.	o.	o.	o.	o.	o.

CUMULATIVE FREQUENCY / FLIGHT HOUR

TABLE 4 TABLE OF VALUES FOR THE TWO DIMENSIONAL DISTRIBUTION OF CORRELATED PARAMETERS

5. ONE PARTICULAR SOLUTION

In Germany an evaluation of Combat-NATO-Manoeuvres has been started with the aim of deriving operational loads by analysing measured parameters in operational flights. These parameters include the time history of the control deflections and the aircraft response. This evaluation is sponsored by the Ministry of Defence and has been performed at the test centre of GAF on one aircraft. The aim is to analyse the possibility of deriving design loads from operational data for combat manoeuvres.

The parameters of the aircraft response should be chosen in a way such that the recording and the evaluation cause minimum expense. This can be achieved by using parameters which are available from the gyro or other existing systems of the aircraft, for example the attitudes (Eulerangles) and/or angular velocities (roll,pitch and yaw rates). In this evaluation 3 attitudes (angle of pitch, bank, heading) the 3 rates of motion (p, q, r) and the control deflections have been recorded and analysed with respect to the feasibility of deriving design loads in this way.

The first results show that 6 parameters, 3 of movement and 3 of control deflections (tailplane, aileron, rudder), together with flight parameters (speed, altitude, thrust) and the aircraft configuration allow one to derive the design loads on the aircraft components. A first feasibility analysis has been made for the derivation of the control deflections from the aircraft response parameters.

The question is: which are the response parameters to start with? There are two possibilities:

Attitudes:	angle of bank Φ	Angular rates:	roll rate p
	angle of pitch Θ		pitch rate q
	angle of yaw Ψ		yaw rate r

Fig. 9 shows the flow diagram of the data analysis for both possibilities. With either of these input sets the derivation of control deflections, aircraft response parameters and loads on aircraft structure is possible. By means of suitable mathematical procedures the measured inputs can be smoothed and differentiated. Using the relationship between attitudes and angular rates of the aircraft motion it is possible to determine control deflection and response parameter time history by numerical integration, if mass parameters and aerodynamic derivatives of the aircraft are known. To start with the attitudes has the following

advantages:

- the description of the aircraft relative to the ground is given in the best way

- compatibility with aircraft handling by pilot and/or with flight manual

disadvantage:

- the necessity to differentiate twice to get the angular acceleration time history

To start with the angular rates has the following

advantage:

- single differentiation leads to higher accuracy in angular acceleration time history

disadvantage:

- the attitudes have to be determinated by numerical integration, which means that the accuracy of their extreme values can be influenced by insufficient precision of measured rates.

As an example for the second possibility the results of this evaluation fo a "High-G-Turn" manoeuvre are shown in figures 1o-11. Fig. 1o shows the inputs, angular rates - measured and smoothed. The control deflections are presented in Fig. 11 for both measured and analysed values for aileron (ξ), rudder (ζ) and elevator ($\Delta\eta$). In Fig. 12 some characteristic response parameters are plotted: Incremental angle of attack ($\Delta\alpha$), lateral load factor (n_y) and incremental vertical load factor (Δn_z) for both measured and analysed values. The load time history presented in figure 13 for two major components (wing and tailplane) show a sufficient approximation between measured and analysed values. These results should be considered only as a first step in the derivation of operational manoeuvre loads by measuring aircraft movement. The continuing objective of the evaluation is to improve the accuracy of values to be measured and the mathematical methods for analysis.

The evaluation procedure might be improved by

- the use of suitable filters for the second differentiation when attitudes are used as input

- availability of a greater number of in-flight measured manoeuvres for each manoeuvre type

- standardization of each manoeuvre type, which means normalising the time history for the input

- evaluation of other manoeuvre types, if possible all Standard-NATO-manoeuvres, applying such procedures

It is intended to extend the application of this method to a second aircraft of the German Air Force.

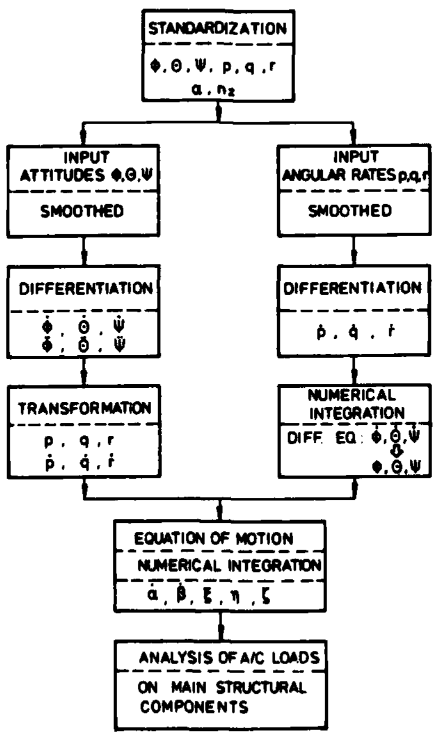

FIG.9 FLOW DIAGRAM OF DATA ANALYSIS

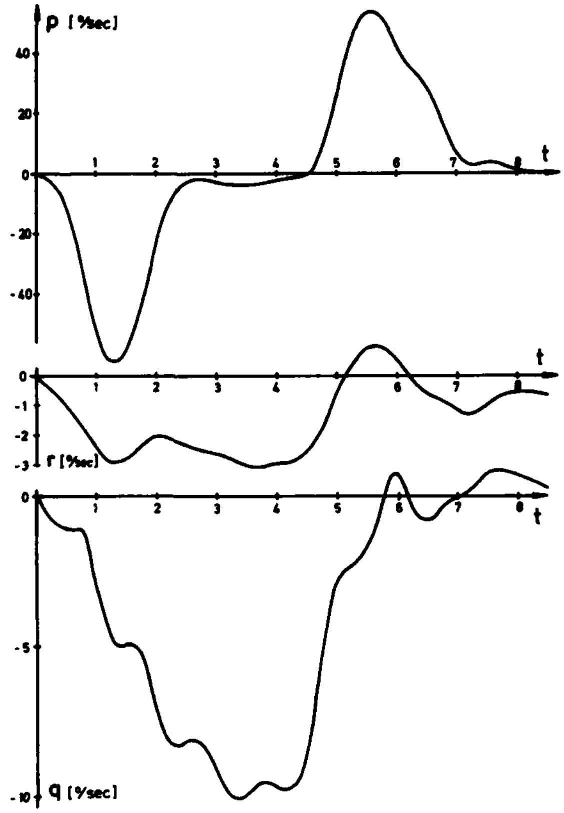

FIG. 10 INPUT ANGULAR RATES MEASURED AND SMOOTHED

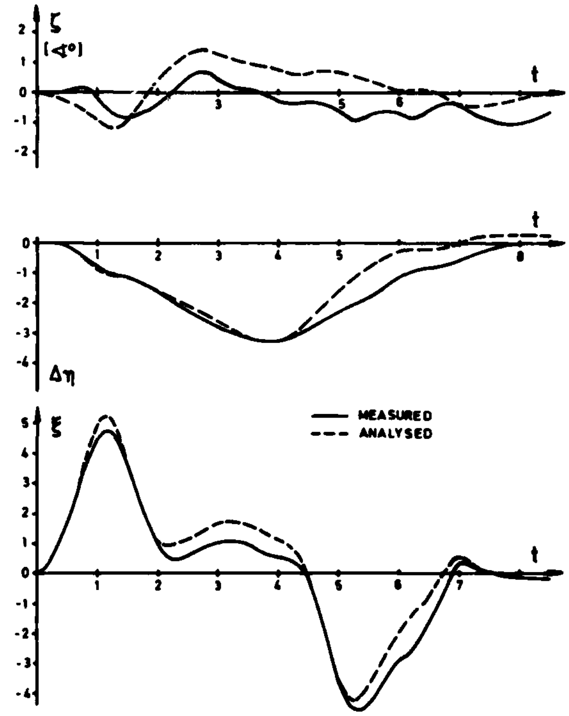

FIG. 11 CONTROL DEFLECTIONS

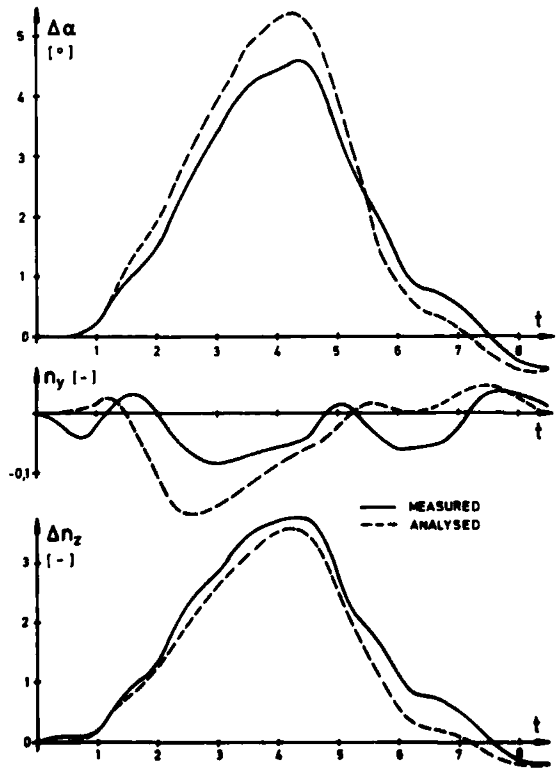

FIG. 12 RESPONSE PARAMETERS

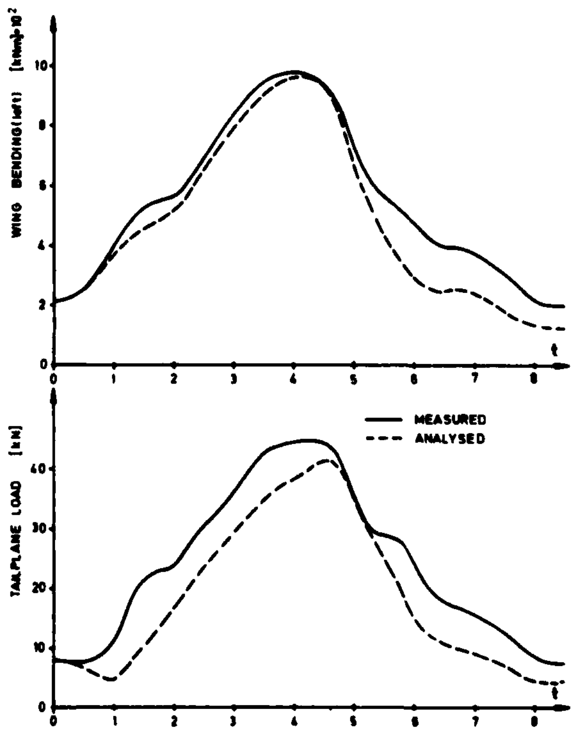

FIG. 13 LOADS ON WING AND TAILPLANE

6. OBJECTIVES

An exchange of experience and expert views on system philosophy, data acquisition technology, data analysis techniques and evaluation of significant results is proposed. Such an exchange would help advance the state of the art on operational loads data acquisition, exploit more fully the information obtained in various programmes to date and allow an initial evaluation of the potential impact of such work on determining design loads, reviewing factors of safety and fatigue calculations.

The major objectives should be:

1. To review existing operational data collections.

2. To compare data acquisition philosophies and techniques, both applied and planned.

3. To compare and to assess alternative approaches of data analysis methods for design loads and fatigue calculations.

For this review two aspects are of particular significance:

1. The cost of measuring the data in service used as input in analysis methods should be as small as possible.

2. The measured parameters must be sufficiently precise and reliable to enable the amplitude and frequency of the loads on all the main structural components of the aircraft to be derived.

7. CONCLUSION

A review of the Questionnaire item concerning Factors of Safety, "What is the relation between the design load level and the loads during operational flights", plainly bears out the fact that the methods so far used to determine design loads as a rule do not correlate at all, or at best marginally, with the loads occurring in the operation of the aircraft.

Parameters suitable for further analysis are indicated. Here, the focus should be on determination of control surface deflections inferred from the associated manoeuvres, where time and cost efficiency is particularly high.

From a present point of view, the following results will be achieved by deriving loads from operational manoeuvres:

- The time history of relevant load parameters, and thus the loads occurring in service, can be determined.

- The relationship of the loads acting on individual primary structural components can be derived from this history.

- The correlation of symmetric and asymmetric loads (z-y) will be apparent from the time history of the loads.

- Systematic recording of suitable parameters will permit specific load evaluation for various missions and/or manoeuvres.

This is a first step towards determination of loads from operational data in service while keeping expenses at a justifiable level. The results obtained so far encourage us to continue our investigations, with improvement of recording and evaluating accuracy being clearly possible.

8. REFERENCES

[1] AGARD - R - 667
Factors of Safety Related to Structural Integrity
A Review of Data from Military Airworthiness Authorities

[2] AGARD - R - 597
A Relation between Measured C.G. vertical Accelerations and the Loads at the T-Tail of a Military Airplane

[3] MIL - A - oo8861A (USAF)
Airplane Strength and Rigidity, Flight Loads

[4] AIR2oo4/E
Resistance des Avions

[5] O. Buxbaum
Verfahren zur Ermittlung von Bemessungslasten schwingbruchgefährdeter Bauteile aus Extremwerten von Häufigkeitsverteilungen
LBF-Bericht Nr. FB-75 (1967)

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14. Abstract

The Structures and Materials Panel is planning to hold a Specialists' Meeting on advanced operational loads data acquisition concepts in Spring 1984. This subject is considered to divide into two major branches: the first, data acquisition and analysis to confirm design loads; the second, extended analysis for fatigue life determination and monitoring systems development. This Report contains two pilot papers, presented at the Spring 1982 Meeting, which, together, characterize both the division into design loads and fatigue analysis, and differing approaches to the determination of operational loads and structural stresses.

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